Application of artificial neural networks in LSC for transactinide research

N. Wiehl[1], G. Langrock[1], K. Eberhardt[1], H.O. Kling[1], J.V. Kratz[1], M. Mendel[1], A. Nähler[1], U. Tharun[1], N. Trautmann[1]

[1] Institut fuer Kernchemie Universitaet Mainz, Germany

norbert.wiehl@uni-mainz.de

Introduction

In Liquid Scintillation Counting (LSC), α- or fission events can be distinguished from β- and γ- events by characteristic differences in their light curves. The reason is a predominant population of triplet states of the scintillator by strong ionizing particles. These triplet states are metastable which leads to a tailing in the light curve (Fig. 1a).

In a common experimental setup for α-LSC, analog pulse shape discrimination (PSD) is used to separate the β/γ- part of the spectrum. However, β/γ- pile up events in a time window of about 150 ns - 250 ns (Fig.1b) can simulate a heavier particle event in the PSD circuit. This leads to a pseudo α-background in the spectrum. Pile ups are occurring randomly at high count rates but can also be produced by decay cascades of a nuclide.

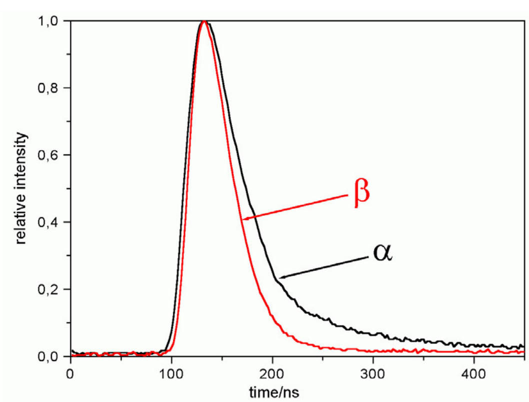

Figure 1a.

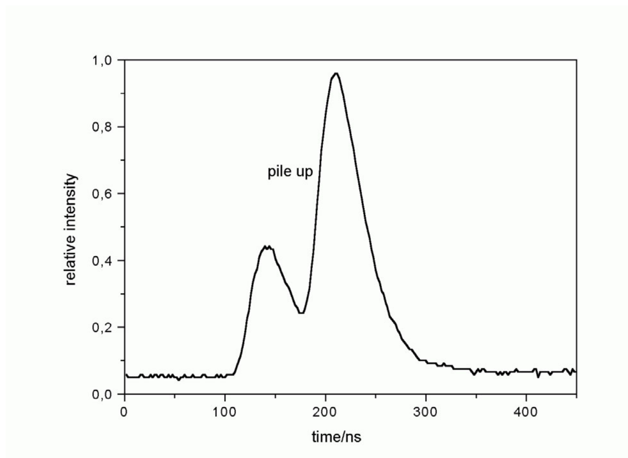

Figure 1b.

In transactinide research with the fast liquid-liquid extraction system SISAK-3 [1], the transactinide element under investigation is extracted into an organic phase containing a liquid scintillator. In these experiments, very few α- decays have to be identified at a high level of β/γ- events. Therefore, any pile up background makes the unambiguous identification of the transactinide nuclides difficult or impossible. In order to apply LSC also in those experiments, the analog PSD has been coupled with a digital pulse recorder. The digitally recorded pulses are off line analysed by an artificial neural network.

Electronics

The setup used is shown schematically in Fig. 2. The photomultiplier (PM), the charge sensitive preamplifier (CSPA), the PSD module, and the time to amplitude converter (TAC), are the standard modules for common LSC. From the built in single channel analyser of the TAC, a trigger signal for the digital pulse recorder is derived. The CSPA integrates the signal. Therefore, it has to be differentated by the timing filter amplifier (TFA) to get the original shape of the signal. As digital pulse recorder, the PC module acqiris DP110 is used. This module allows a maximum sampling rate of 1 GS/s at a bandwidth of 500 MHz. Besides the pulse also the time of the corresponding trigger event is recorded which allows the search for correlated events.

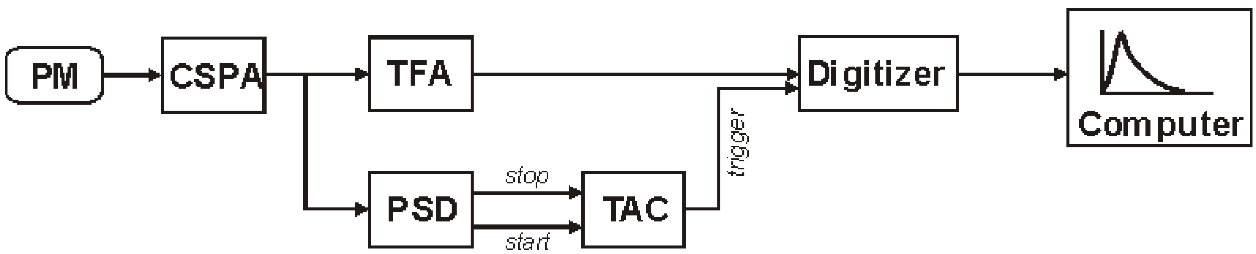

Figure 2.

Artificial neural network

Artificial neural networks are successfully used for pattern recognition especially if an analytical description of the characteristics of the patterns is difficult or impossible. The artificial model of a neuron is rather simple. Each input to a neuron is multiplied by a weighting factor. The weights are corresponding to the synaptic strength in a natural neural network. The output is some function, the so called transfer function, of the weighted sum of all inputs. The weights are initialized by some random values. Learning of the network means adjusting the weighting factors.

For the digital pulse shape discrimination with neural networks (PSD-NN), a 3 layer feed forward network was modeled with the program SMART [2]. The input layer has 175 neurons corresponding to 175 samples at every 2 ns of a pulse. The second (hidden) layer has 5 neurons, and the output layer has two neurons corresponding to an alpha event and any other type of event, respectively. Each output of a layer is connected to each neuron of the next higher layer. The sigmoid function is used as transfer function which gives output values between 0 and 1. The weights are adjusted during the training phase with the backpropagation algorithm [3]. In principle, the weights are corrected in proportion to the error of the network, i.e., the difference between the current and correct output for a given training pattern. This error is propagated backwards from the output layer to the inner layers in order to dertermine correction values for all weights of all layers. Taining patterns for α-events were recorded from a ^{219}Rn / ^{215}Po source. Training data for β-, γ-, and pile up events were recorded mostly from neutron irradiated dibutylphosphate (DBP) solved in toluene. All pulses are normalized to a fixed amplitude thus avoiding that the network learns an energy calibration. After each training cycle the network was tested with test data recorded from the same sources. Fig. 3 shows the error of the network with proceeding training. The errror decreases very rapidly and is almost constant after 600 iterations.

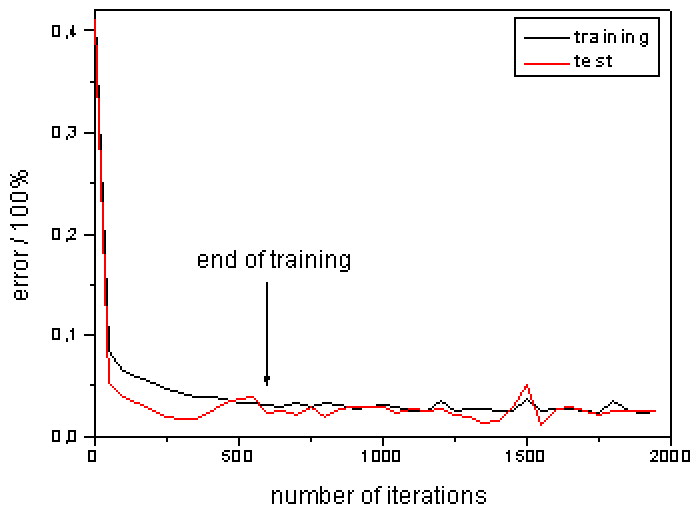

Figure 3.

Test experiment and results

The PSD-NN system was first tested in a SISAK experiment at the Paul Scherrer Institute in February 2000. In this experiment, rutherfordium was produced in the reaction $^{248}Cm(^{18}O,5n)^{261}Rf$ (E_a=8.8 MeV, $T_{1/2}$=78 s). Fig. 4 shows the setup schematically.

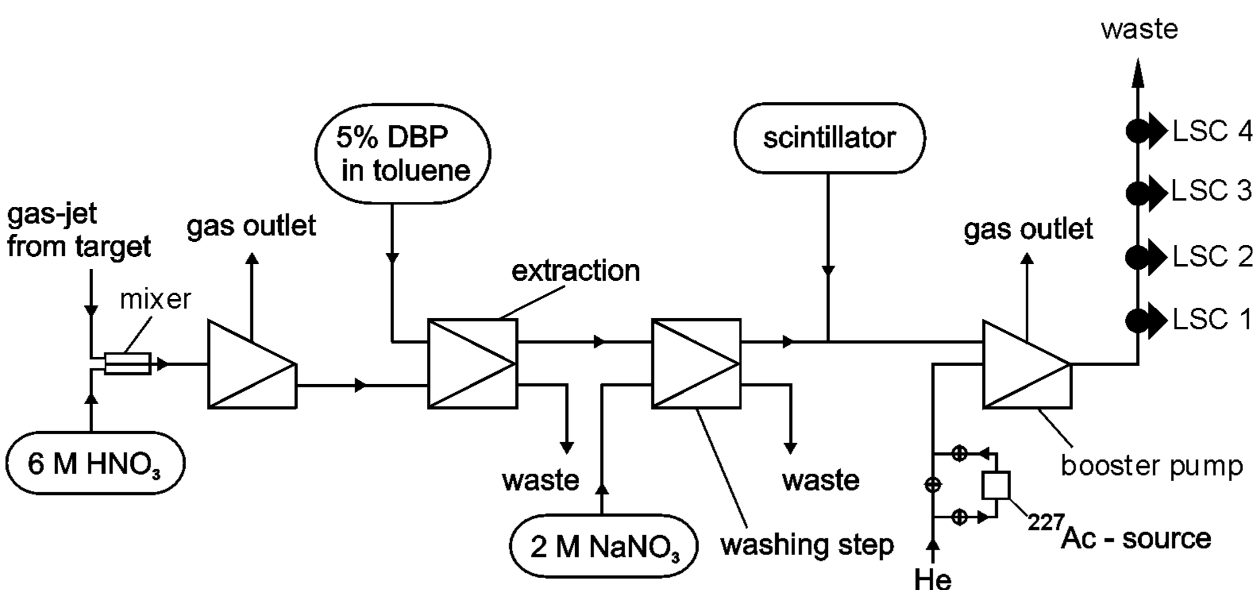

Figure 4.

The reaction products transported with a gas - jet are dissolved in 6M HNO_3. Group IV elements are then extracted with 5% DBP in toluene. In a washing step with 2 M $NaNO_3$ the remaining nitric acid is removed. Then, the scintillator consisting of dimethylPOPOP (3g/l) and methylnaphtalene (30vol%) dissolved in toluene is added. In this experiment, 4 detector cells of 5.5 ml each connected in series are used with the analog PSD electronics. The first detector was also connected to the digital pulse recorder.

The power of the artificial neural network is demonstrated in Fig. 5. Fig 5a shows a typical "α-spectrum" in the energy range of interest from the analog PSD. In Fig. 5b the same spectrum is shown after treatment with the neural network. In the total spectrum 95.8% of the events could be identified as pile up events. These results show that low level α-LSC can be significantly improved by the application of digital pulse recording in combination with artificial neural networks.

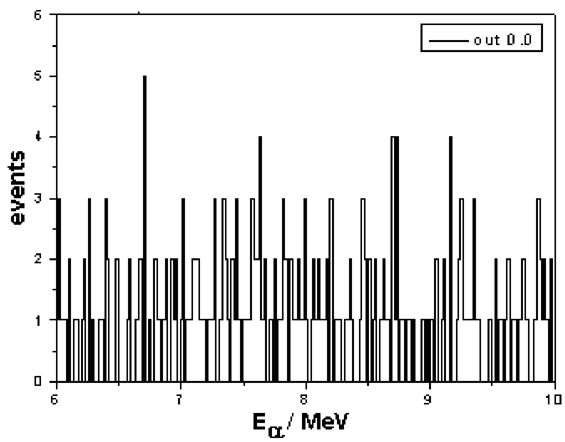

Figure 5a.

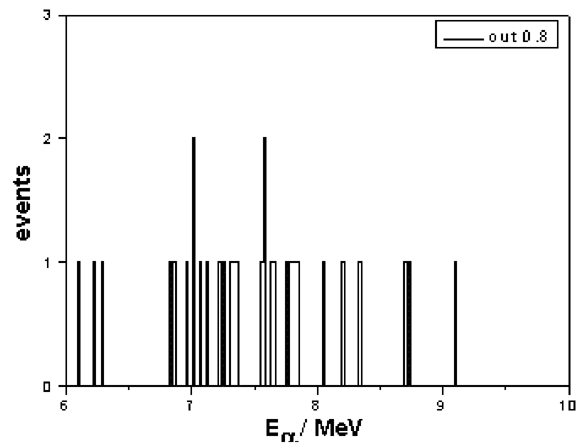

Figure 5b.

A new application of LSC with the digital recording of pulses is the determination of spectroscopic data. Pile ups are often associated with coincident nuclear transistions. If these transitions occur in the nanosecond regime, a pile up can be resolved such that the two radiations can be separated.This enables one to determine lifetimes of excited states. An example is given in Fig. 6 for a measurement of ^{241}Am. The α-decay of ^{241}Am populates the $5/2^-$ level in ^{237}Np at 59.5 keV having a lifetime of 67 ns. This correlated α-γ decay produces pile ups in the scintillator. Fig. 6a gives an example. From the distance between the two peaks, a time difference Δt can be determined. The number of pile ups of a given Δt plotted vs. Δt is shown in Fig. 6b. From the fit of an exponential decay law to these data, the lifetime of the excited state can be determined to 67 ns in good ageement with published data. Thus, this application is promising as it allows the determination of hitherto unknown decay properties of short - lived nuclei.

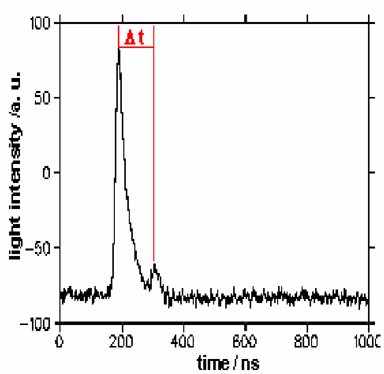

Figure 6a.

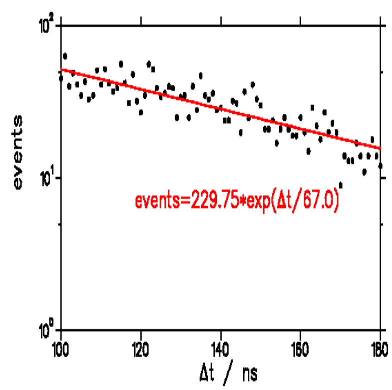

Figure 6b.

References

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